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EXPOSURE METHOD AND APPARATUS

TECHNICAL FIELD

The present invention relates to an exposure method and an exposure apparatus to be used in the step for transferring a mask pattern onto a substrate such as a wafer when a device, which includes, for example, semiconductor integrated circuits, image pickup elements (for example, CCD), liquid crystal displays, plasma displays, and thin film magnetic heads, is produced by using the lithography technique. The present invention is preferably used especially when a vacuum ultraviolet light beam (VUV light beam) is used as an exposure light beam.

BACKGROUND ART

In order to enhance the resolution in response to the realization of fine circuits, the wavelength of the exposure light beam as an exposure beam is gradually shifted toward the short wavelength side in the projection exposure apparatus to be used when a semiconductor integrated circuit or the like is produced. At present, the KrF excimer laser (wavelength: 248 nm) is predominantly used. However, the ArF excimer laser (wavelength: 193 nm), which has the shorter wavelength in the vacuum ultraviolet region, is almost at the

stage of practical use. Projection exposure apparatuses have been also suggested, which use the exposure light beam having a shorter wavelength in the vacuum ultraviolet region, i.e., in a wavelength band of not more than about 180 nm, including, for example, the F_2 laser (wavelength: 157 nm) and the Ar_2 laser (wavelength: 126 nm) each having the shorter wavelength.

In the case of the ordinary optical glass, the transmittance is lowered for the exposure light beam having the wavelength of not more than about 180 nm as described above. The optical material, which can be used for the refractive optical member and the substrate for the reticle as a transmissive type photomask, is limited, for example, to quartz glass doped with, for example, fluorine, and crystals of fluorite (CaF_2), magnesium fluoride (MgF_2), and lithium fluoride (LiF). Further, the exposure light beam, which has a wavelength of not more than about 200 nm as in the vacuum ultraviolet region, is also absorbed extremely greatly, for example, by the gas based on oxygen, steam, and hydrocarbon (hereinafter referred to as "absorptive gas"). Therefore, for example, it is necessary for oxygen that the average concentration in the optical path is suppressed to be approximately in an order of ppm. Accordingly, when the vacuum ultraviolet light beam is used as the exposure light beam, it is necessary that the optical path for the exposure light beam is substantially in vacuum, or the gas containing

the absorptive gas such as oxygen on the optical path is substituted with a gas which causes less absorption. When the entire optical path for the exposure light beam is substantially in vacuum, it is necessary to provide a pressure-reducing chamber (preparatory chamber) for exchanging the photomask and the wafer, for example, because the library of the photomask and the transport line for the wafer as the substrate to be exposed are arranged in the air. For this reason, it takes a long period of time to exchange the photomask and the wafer, resulting in the decrease in throughput of the exposure step. Accordingly, consideration will be made below for the case in which the gas on the optical path for the exposure light beam is substituted with the gas which causes less absorption, i.e., the gas through which the exposure light beam is transmitted.

In the case of the projection exposure apparatus which uses, as the exposure light beam, the light beam having the wavelength of not more than about 180 nm even in the vacuum ultraviolet region as described above, it is necessary that the predetermined optical material, which causes less absorption, is used for the refractive optical member and the substrate for the reticle, and the gas on the optical path is substituted with the gas which causes less absorption, in order to suppress the absorption of the exposure light beam on the optical path so that the high illuminance is obtained on the wafer. However, for example, if the residual

concentration of the absorptive gas in the gas on the optical path exceeds a predetermined normalized value, for example, due to the contamination of the gas on the optical path with the external air which absorbs the exposure light beam, or due to the generation of the release gas containing the absorptive gas which absorbs the exposure light beam, for example, from the inner wall of the lens barrel contacting with the optical path, then the exposure energy on the wafer (substrate to be exposed) is remarkably lowered. It is also feared that the absorptance of the exposure light beam in the optical path may be varied by the time-dependent change of the residual concentration of the absorptive gas or by any uneven distribution in the optical path, the exposure energy on the wafer may become unstable, and any uneven illuminance may occur in the exposure shot.

On the other hand, in relation to the gas substitution for the optical path, there have been suggested a method in which the gas (for example, nitrogen or rare gas), through which the vacuum ultraviolet light beam as the exposure light beam is transmitted, is allowed to continuously flow for several hours during the exposure, and a method in which the mechanism for tightly enclosing the optical path of the projection exposure apparatus is allowed to have pressure resistance, and the gas is charged after the interior in the optical path is previously evacuated in vacuum. However, in the case of the method in which the gas is allowed to

continuously flow as in the former method, the following inconvenience arises. That is, the gas is allowed to flow for a long period of time, the amount of consumption of the gas is increased, and the running cost is increased. Especially, an expensive gas such as helium is used for the gas, the running cost for the projection exposure apparatus is greatly increased.

In the case of the method in which the interior of the optical path is once in vacuum to fill the interior with the gas through which the exposure light beam is transmitted as in the latter method, the following problem occurs. That is, any impurity, which absorbs the exposure light beam, is released from the constitutive material for the lens barrel or the like of the optical system during the process in which the pressure is reduced to vacuum, and the surfaces of the lens and the mirror are polluted with the impurity.

Even when the gas substitution is performed without performing the vacuum evacuation, any impurity or the like, which has adsorbed to the surface of the constitutive material, is released to some extent in a state (steady state) in which the interior is filled with the gas through which the exposure light beam is transmitted after the completion of the gas substitution. For this reason, it is also necessary to continuously remove the impurity by successively circulating (substituting) the gas in the optical path at a predetermined rate after the completion of

the gas substitution.

Taking the foregoing viewpoints into consideration, a first object of the present invention is to provide an exposure method which makes it possible to perform substitution in a stable manner when a gas on at least a part of optical path for an exposure light beam is substituted with a gas through which the exposure light beam is transmitted.

A second object of the present invention is to provide an exposure method which makes it possible to perform substitution at less running cost when a gas on at least a part of optical path for an exposure light beam is substituted with a gas through which the exposure light beam is transmitted.

A third object of the present invention is to provide an exposure apparatus which makes it possible to carry out the exposure method as described above easily or efficiently, and a method for producing the exposure apparatus.

A fourth object of the present invention is to provide a method for producing a device, which makes it possible to produce the device at a high illumination efficiently and consequently at a high throughput by using the exposure method as described above.

DISCLOSURE OF THE INVENTION

Sub A1

~~A first exposure method according to the present invention resides in an exposure method for illuminating a first object (41) with an exposure light beam and exposing a second object (61) with the exposure light beam having passed through a pattern on the first object; the exposure method comprising tightly enclosing a space (BMU to WST) which includes at least a part of an optical path for the exposure light beam; and filling the tightly enclosed space with a predetermined gas through which the exposure light beam is transmitted, until a gas pressure approximate to a first gas pressure (P1) is obtained, by alternately repeating, a plurality of times, a pressure-reducing step of reducing a pressure of a gas in the tightly enclosed space until a gas pressure approximate to a second gas pressure (P2) lower than the first gas pressure is obtained; and a filling step of supplying the predetermined gas to the tightly enclosed space until an intermediate gas pressure (P3) between the first gas pressure and the second gas pressure is obtained.~~

According to the present invention as defined above, the pressure-reducing step and the filling step are repeated, for example, twice or more, without bringing about the high vacuum for the second gas pressure. Accordingly, the space can be filled with the gas at a high purity through which the exposure light beam, which is composed of, for example, a light beam having a wavelength of not more than 200 nm, is transmitted. During this process, the interior of the space

is not in a high vacuum state. Therefore, the amount of the release gas containing any impurity generated, for example, from wall members for the space is decreased. It is possible to stably perform the substitution for the gas in the space.

In this case, the first gas pressure (P1) is, for example, 900 hPa to 1100 hPa, i.e., approximately 1 atm. (atmospheric pressure). The second gas pressure (P2) is, for example, within a range of 50 Pa to 10 kPa, i.e., approximately 0.1 to 0.01 atm. It is unnecessary that the second gas pressure is extremely in the high vacuum.

Sub A2

In another aspect, a second exposure method according to the present invention resides in an exposure method for illuminating a first object (41) with an exposure light beam and exposing a second object (61) with the exposure light beam having passed through a pattern on the first object; the exposure method comprising tightly enclosing a space (BMU to WST) which includes at least a part of an optical path for the exposure light beam; the exposure method further comprising a first step of substituting the tightly enclosed space with a first gas through which the exposure light beam is transmitted; and a subsequent second step of substituting the tightly enclosed space with a second gas through which the exposure light beam is transmitted, the second gas being different from the first gas.

Sub A3

According to the present invention as defined above, when the gas in the space is substituted with the gas through

which the exposure light beam is transmitted, it is possible to decrease the amount of use of the second gas. Therefore, the running cost can be reduced by using, for example, the second gas of a gas which is more expensive than the first gas but which has a better transmittance with respect to the exposure light beam as compared with the first gas.

In still another aspect, a first exposure apparatus according to the present invention resides in an exposure apparatus for illuminating a first object (41) with an exposure light beam and exposing a second object (61) with the exposure light beam having passed through a pattern on the first object; the exposure apparatus comprising a gas-tight chamber (2 to 6) which tightly encloses a space (BMU to WST) including at least a part of an optical path for the exposure light beam; and a gas supply unit (S2 to S6) which supplies a predetermined gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber; wherein the gas supply unit has an impurity-removing filter including a light-absorbing gas-removing filter (15) which removes at least one of oxygen and steam contained in the predetermined gas.

The exposure apparatus is used to circulate the gas in the gas-tight chamber after performing the substitution for the gas by using, for example, the exposure method as described above. Accordingly, it is possible to maintain a high purity state of the gas in the gas-tight chamber.

A4

In still another aspect, a second exposure apparatus according to the present invention resides in an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the exposure apparatus comprising a gas-tight chamber (2 to 6) which tightly encloses a space (BMU to WST) including at least a part of an optical path for the exposure light beam; a gas supply unit (S2 to S6) which supplies a predetermined gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber; a gas concentration-measuring unit (112) which measures a concentration of a predetermined residual gas remaining in the space in the gas-tight chamber; and an opening/closing mechanism (V13, V14) which opens/closes a passage for the gas between the space in the gas-tight chamber and the gas concentration-measuring unit.

According to the second exposure apparatus as defined above, for example, when the gas pressure in the space is lowered in order to exchange the gas in the space, the gas concentration-measuring unit can be protected by closing the opening/closing mechanism to separate the gas concentration-measuring unit from the space. Therefore, when the exposure method of the present invention described above is carried out, it is possible to stably measure the gas concentration in the gas-tight chamber.

In still another aspect, a third exposure apparatus according to the present invention resides in an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the exposure apparatus comprising a gas-tight chamber (2 to 6) which tightly encloses a space (BMU to WST) including at least a part of an optical path for the exposure light beam; a gas supply unit (S2 to S6) which supplies a predetermined gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber; an openable/closable cutoff valve (V12, V1) which is provided in a supply passage for the predetermined gas to be supplied by the gas supply unit; and a control unit (17, 18) which closes the cutoff valve in case of emergency and in case of maintenance for the exposure apparatus to stop the supply of the predetermined gas to the gas-tight chamber. According to the exposure apparatus as defined above, the interior of the gas-tight chamber can be filled with the gas through which the exposure light beam is transmitted, in a short period of time by closing the cutoff valve in case of emergency and in case of maintenance, introducing the external air into the gas-tight chamber to perform predetermined operation, and then opening the cutoff valve again. Therefore, it is possible to efficiently carry out the exposure method of the present invention.

In still another aspect, a fourth exposure apparatus according to the present invention resides in an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the exposure apparatus comprising a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; and a gas supply unit which supplies a predetermined gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber until a gas pressure approximate to a first gas pressure is obtained; wherein the gas supply unit includes a pressure-reducing mechanism which reduces a gas pressure of a gas in the gas-tight chamber to a second gas pressure that is lower than the first gas pressure, a filling mechanism which fills the interior of the gas-tight chamber with the predetermined gas until an intermediate gas pressure between the first gas pressure and the second gas pressure is obtained, and a control unit which controls the pressure-reducing mechanism and the filling mechanism so that the reduction of the gas pressure and the filling with the predetermined gas are repeated a plurality of times.

In still another aspect, a fifth exposure apparatus according to the present invention resides in an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure

light beam having passed through a pattern on the first object; the exposure apparatus comprising a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; a first gas supply unit which supplies a first gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber; a second gas supply unit which supplies a second gas which is different from the first gas and through which the exposure light beam is transmitted, to the interior of the gas-tight chamber; and an adjusting unit which adjusts amounts of the supply of the gasses to be supplied by the first and second gas supply units.

The first and second exposure methods of the present invention can be carried out by using the fourth and fifth exposure apparatuses respectively.

A7

~~In still another aspect, a method for producing a device according to the present invention resides in a method for producing a device, comprising the step of transferring a device pattern onto a workpiece (61) by using the exposure method of the present invention or the exposure apparatus of the present invention. When the exposure method of the present invention is used, then the transmittance of the optical path for the exposure light beam is maintained to be high, and the illuminance (exposure energy) of the exposure light beam on the workpiece is maintained to be high. Therefore, the throughput of the exposure step is improved,~~

and it is possible to produce the device at the high throughput.

In still another aspect, a method for producing the first exposure apparatus according to the present invention resides in a method for producing an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the production method comprising assembling, in a predetermined positional relationship, a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; and a gas supply unit which supplies a predetermined gas through which the exposure light beam is transmitted, the gas supply unit having an impurity-removing filter including a light-absorbing gas-removing filter which removes at least one of oxygen and steam contained in the predetermined gas.

In still another aspect, a method for producing the second exposure apparatus according to the present invention resides in a method for producing an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the production method comprising assembling, in a predetermined positional relationship, a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam

exposure light beam; a gas supply unit which supplies a predetermined gas through which the exposure light beam is transmitted; a gas concentration-measuring unit which measures a concentration of a predetermined residual gas remaining in the space in the gas-tight chamber; and an opening/closing mechanism which opens/closes a passage for the gas between the space in the gas-tight chamber and the gas concentration-measuring unit.

In still another aspect, a method for producing the third exposure apparatus according to the present invention resides in a method for producing an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the production method comprising assembling, in a predetermined positional relationship, a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; a gas supply unit which supplies a predetermined gas through which the exposure light beam is transmitted; an openable/closable cutoff valve which is provided in a supply passage for the predetermined gas to be supplied by the gas supply unit; and a control unit which closes the cutoff valve in case of emergency and in case of maintenance for the exposure apparatus to stop the supply of the predetermined gas to the gas-tight chamber.

In still another aspect, a method for producing the

fourth exposure apparatus according to the present invention resides in a method for producing an exposure apparatus for illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the production method comprising assembling, in a predetermined positional relationship, a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; and a gas supply unit which supplies a predetermined gas through which the exposure light beam is transmitted, to interior of the gas-tight unit until a gas pressure approximate to a first gas pressure is obtained, the gas supply unit including a pressure-reducing mechanism which reduces a gas pressure of a gas in the gas-tight chamber to a second gas pressure that is lower than the first gas pressure, a filling mechanism which fills the interior of the gas-tight chamber with the predetermined gas until an intermediate gas pressure between the first gas pressure and the second gas pressure is obtained, and a control unit which controls the pressure-reducing mechanism and the filling mechanism so that the reduction of the gas pressure and the filling with the predetermined gas are repeated a plurality of times.

In still another aspect, a method for producing the fifth exposure apparatus according to the present invention resides in a method for producing an exposure apparatus for

illuminating a first object with an exposure light beam and exposing a second object with the exposure light beam having passed through a pattern on the first object; the production method comprising assembling, in a predetermined positional relationship, a gas-tight chamber which tightly encloses a space including at least a part of an optical path for the exposure light beam; a first gas supply unit which supplies a first gas through which the exposure light beam is transmitted, to interior of the gas-tight chamber; a second gas supply unit which supplies a second gas which is different from the first gas and through which the exposure light beam is transmitted, to the interior of the gas-tight chamber; and an adjusting unit which adjusts amounts of the supply of the gasses to be supplied by the first and second gas supply units.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic arrangement illustrating a projection exposure apparatus to be used in an exemplary embodiment of the present invention. Fig. 2 shows an arrangement illustrating a representative gas substitution unit S of those shown in Fig. 1 and a corresponding gas-tight unit 8. Fig. 3 shows an exemplary arrangement of a concentration meter 11A (or a concentration meter 11B) shown in Fig. 2. Fig. 4 shows a state of change of the gas

pressure in the gas-tight unit when the pressure-reducing step and the filling step with the low absorption gas are repeated in the embodiment of the present invention. Fig. 5 shows a flow chart illustrating the gas substitution operation for the gas-tight unit in the embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

An exemplary preferred embodiment of the present invention will be explained below with reference to the drawings. In this embodiment, the present invention is applied to a case in which the exposure is performed with a projection exposure apparatus which uses, as an exposure light beam, a light beam having a wavelength of not more than 200 nm, i.e., a light beam which can be substantially regarded as a vacuum ultraviolet light beam (VUV light beam).

Fig. 1 shows a schematic arrangement illustrating the projection exposure apparatus of this embodiment. With reference to Fig. 1, the F_2 laser (fluorine laser) having an oscillation wavelength of 157 nm is used as an exposure light source 1. However, those usable as the exposure light beam 1 include light sources for generating other vacuum ultraviolet light beams such as the Kr_2 laser (krypton dimer laser) having a wavelength of 146 nm and the Ar_2 laser (argon dimer laser) having a wavelength of 126 nm as well as the high

harmonic wave generator for the YAG laser and the high harmonic wave generator for the semiconductor laser. An exposure light beam IL, which is composed of an ultraviolet laser beam as an exposure beam generated from the exposure light source 1, illuminates a reticle 41 as a mask via a beam matching unit BMU and an illumination optical system ILU. The exposure light beam IL, which has passed through the reticle 41, forms a reduction image of a pattern on the reticle 41 on a wafer 61 as a substrate to be exposed, via a projection optical system PL. The reticle 41 and the wafer 61 correspond to the first object and the second object of the present invention. The following description will be made assuming that the Z axis extends in parallel to the optical axis AX of the projection optical system PL, the X axis extends in parallel to the plane of paper of Fig. 1 in a plane perpendicular to the Z axis, and the Y axis extends perpendicularly to the plane of paper of Fig. 1.

At first, in the beam matching unit BMU, the exposure light beam IL from the exposure light source 1 passes along a relay lens 21, an optical path-bending mirror 22, a relay lens 23, and a relay lens 24, and the exposure light beam IL is directed to the illumination optical system ILU. In the illumination optical system ILU, the exposure light beam IL from the beam matching unit BMU comes into a fly's eye lens 31 as an optical integrator (homogenizer). An aperture diaphragm (σ diaphragm) 32 of the illumination system is

arranged at a light-exit plane of the fly's eye lens 31. A rod lens may be used in place of the fly's eye lens 31.

The exposure light beam IL, which has passed through the aperture diaphragm 32, arrives at a field diaphragm (reticle blind) 36 via a relay lens 33, an optical path-bending mirror 34, and a relay lens 35. The exposure light beam IL, which has passed through the field diaphragm 36, illuminates the reticle 41 via a condenser lens 37, an optical path-bending mirror 38, and a condenser lens 39. The beam matching unit BMU and the illumination optical system ILU described above are tightly enclosed in a state of being isolated from the external air in a first gas-tight unit 2 and a second gas-tight unit 3 each of which has high gas tightness, each of which has predetermined pressure resistance, and each of which has a box-shaped configuration.

The reticle 41 is held on a reticle stage 42 by means of, for example, the vacuum attraction. The reticle stage 42 is placed so that the reticle stage 42 is continuously movable (capable of scanning) in the X direction and finely movable in the X direction, the Y direction, and the direction of rotation on a reticle base 43. The positions in the X direction and the Y direction and the angles of rotation about the three axes of the reticle stage 42 are measured by unillustrated laser interferometers. An unillustrated reticle stage-driving system controls the operation of the reticle stage 42 on the basis of obtained

measured values and control information supplied from an unillustrated main control system which collectively controls the operation of the entire apparatus. A reticle stage system RST is constructed by the reticle stage 42 and the reticle base 43. The reticle stage system RST is covered with a box-shaped reticle stage chamber 4 composed of partition walls having high gas tightness so that the reticle stage system RST is isolated from the external air. The reticle stage chamber 4 can be also referred to as "third gas-tight unit 4".

The wafer 61 is exposed to an image obtained by reducing a pattern in an illumination area on the reticle 41 at a projection magnification β (β is, for example, 1/4, 1/5, or 1/6) via the projection optical system PL with the exposure light beam IL which has passed through the reticle 41. The projection optical system PL comprises lens systems 51, 52, 53, 54 which are arranged in this order from the side of the reticle 41 along the optical axis AX. A photoresist (photosensitive material) is applied on the wafer 61. The wafer 61 is a disk-shaped substrate composed of, for example, semiconductor (for example, silicon) or SOI (silicon on insulator). The projection optical system PL is accommodated in a lens barrel 5 which has high gas tightness and which has high pressure resistance in a state in which the projection optical system PL is isolated from the external air. The lens barrel 5 can be also referred to as "fourth gas-tight

unit".

On the other hand, the wafer 61 is held on a wafer holder 62 by means of, for example, the vacuum attraction. The wafer holder 62 is fixed on a wafer stage 63. The wafer stage 63 is placed on an unillustrated wafer base so that the wafer stage 63 is continuously movable (capable of scanning) in the X direction and movable in the X direction and the Y direction in a stepping manner. The positions in the X direction and the Y direction and the angles of rotation about the three axes (yawing amount, pitching amount, and rolling amount) of the wafer stage 63 are measured by unillustrated laser interferometers. An unillustrated wafer stage-driving system controls the operation of the wafer stage 63 on the basis of obtained measured values and control information supplied from the unillustrated main control system. Further, the wafer stage 63 focuses the surface of the wafer 61 with respect to the image plane of the projection optical system PL on the basis of a measured value obtained by an unillustrated autofocus sensor. The wafer stage system WST is constructed, for example, by the wafer holder 62, the wafer stage 63, and the wafer base (not shown). The wafer stage system WST is covered with a box-shaped wafer stage chamber 6 composed of partition walls having high gas tightness so that the wafer stage system WST is isolated from the external air. The wafer stage chamber 6 can be also referred to as "fifth gas-tight unit 4".

During the exposure, the operation for scanning one shot area on the wafer 61 in the X direction at a constant velocity $\beta \cdot VR$ (β represents the projection magnification of the projection optical system PL) in synchronization with the scanning of the reticle 41 in the X direction at a constant velocity VR, and the operation for moving the wafer 61 in a stepping manner to move the next shot area to the scanning start position are repeated in accordance with the step-and-scan system. All of the shot areas on the wafer 61 are subjected to the exposure. The projection exposure apparatus of this embodiment is based on the scanning exposure system as described above. However, it is needless to say that the present invention is also applicable to a projection exposure apparatus of the full field exposure type such as a stepper.

When the light beam in the vacuum ultraviolet region is used for the exposure light beam IL as in this embodiment, it is necessary that the substance which has a large absorptance (i.e., has a low transmittance) with respect to the exposure light beam IL, i.e., the "absorptive gas" such as oxygen, steam, and hydrocarbon-based gas is excluded from the optical path. Accordingly, the projection exposure apparatus of this embodiment is provided with a gas supply unit for supplying, to the optical path, the gas through which the exposure light beam IL is transmitted, i.e., the gas having a low absorptance with respect to the light beam in the vacuum ultraviolet region (hereinafter referred to as "low

absorption gas"). Those usable as the low absorption gas in this embodiment include the so-called inert gas, i.e., nitrogen gas (N_2) and rare gases including helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). A mixed gas, which is composed of two or more inert gases, may be used as the low absorption gas.

A gas supply mechanism of this embodiment will now be explained. With reference to Fig. 1, an upper part of the first gas-tight unit 2 of the projection exposure apparatus of this embodiment, the second gas-tight unit 3, the reticle stage chamber 4, the lens barrel 5 of the projection optical system PL, and the wafer stage chamber 6 are installed in a certain clean room in a semiconductor production factory. The exposure light source 1 and a lower part of the first gas-tight unit 2 are installed in a machine room disposed under the floor of the clean room. A first gas source (not shown) for generating a first low absorption gas GA through which the light beam in the vacuum ultraviolet region is transmitted, and a second gas source (not shown) for generating a second low absorption gas GB which is different from the first low absorption gas GA and through which the light beam in the vacuum ultraviolet region is transmitted are installed in the machine room. The first low absorption gas GA and the second low absorption gas GB are supplied to gas substitution units S2, S3, S4, S5, S6 via a first piping 9A and a second piping 9B respectively. The gas substitution

units S2, S3, S4, S5, S6 are connected, via gas supply tubes Sin and gas discharge tubes Sen (n = 2 to 6), to the first gas-tight unit 2 for surrounding the beam matching unit BMU, the second gas-tight unit 3 for surrounding the illumination optical system ILU, the reticle stage chamber 4 for surrounding the reticle stage system RST, the lens barrel 5 for surrounding the projection optical system PL, and the wafer stage chamber 6 for surrounding the wafer stage system WST respectively. The gas substitution units S2 to S6 substitute the gas in the corresponding gas-tight units (gas-tight unit 2 to wafer stage chamber 6) respectively.

In this embodiment, for example, nitrogen gas is used as the first low absorption gas GA, and rare gas such as helium or neon is used as the second low absorption gas GB. In this case, the refractive indexes of the respective gases described above (values with respect to the D-ray) are as follows.

Nitrogen (N_2): 1.000297

Neon (Ne): 1.000067

Helium (He): 1.000035

The coefficients of thermal conductivity of the respective gases at 0 °C are as follows.

Nitrogen: 2.40

Neon: 4.65

Helium: 14.22

As appreciated from the above, the refractive index of

the second low absorption gas GB (rare gas) is smaller than that of the first low absorption gas GA (nitrogen), and the amount of variation of the refractive index of the second low absorption gas GB with respect to, for example, any variation of atmospheric pressure is also smaller than that of the first low absorption gas GA. Therefore, the second low absorption gas GB is advantageous, for example, in that the image formation characteristics of the projection optical system PL are stabilized. Further, the second low absorption gas GB has the good coefficient of thermal conductivity and the good heat release effect as compared with the first low absorption gas GA. Therefore, the second low absorption gas GB is also excellent in stability of the temperature of the internal optical members or the like. However, in the present circumstances, the second low absorption gas GB is more expensive than the first low absorption gas GA. Therefore, in order to reduce the running cost for the exposure apparatus, it is desirable to reduce the amount of consumption of the second low absorption gas GB. Accordingly, for example, a first operation method may be available as follows. That is, the cheap first low absorption gas GA is principally supplied to the portion in which the internal space has the large volume but the image formation characteristics are not affected thereby so much, such as the first gas-tight unit 2, the second gas-tight unit 3, the reticle stage chamber 4, and the wafer stage chamber

6. The high performance second low absorption gas GB is principally supplied to the portion in which the internal space does not have the large volume so much but it is necessary to maintain the high image formation characteristics therein, such as the interior of the lens barrel 5 of the projection optical system PL. Accordingly, it is possible to obtain the high image formation characteristics while suppressing the running cost.

Alternatively, for example, a second operation method may be available as follows. That is, almost all of the internal gas is firstly substituted with the cheap first low absorption gas GA in all of or any one of the gas-tight units 2, 3, the reticle stage chamber 4, the lens barrel 5 of the projection optical system PL, and the wafer stage chamber 6. After that, the substitution is performed with the high performance second low absorption gas GB. In this case, even when the first low absorption gas GA remains to some extent, the transmittance of the exposure light beam IL is scarcely affected thereby. Therefore, it is unnecessary to perform the substitution with the second low absorption gas GA extremely strictly. Accordingly, it is possible to decrease the amount of use of the second low absorption gas GB as compared with a case in which the substitution is performed with the second low absorption gas GB from the beginning. It is possible to obtain the high image formation characteristics while suppressing the running cost.

Further alternatively, for example, a third operation method may be available as follows. That is, the substitution is performed with a gas obtained by mixing, at a predetermined rate, the cheap first low absorption gas GA and the high performance second low absorption gas GB in all of or any one of the gas-tight units 2, 3, the reticle stage chamber 4, the lens barrel 5 of the projection optical system PL, and the wafer stage chamber 6. Even in the case of this method, it is possible to obtain, for example, relatively high image formation performance while suppressing the amount of consumption of the second low absorption gas GB.

A gas aspirator 7, which includes, for example, a vacuum pump, is connected to the gas substitution units S2 to S6 via a discharging piping 9C1 or 9C2. The gas, which contains the absorptive gas or the like from the gas substitution units S2 to S6, can be discharged by using the gas aspirator 7. The gas GC, which is discharged by the gas aspirator 7, is discharged via a piping 9D, for example, to a discharging piping (not shown) in the semiconductor factory in which the projection exposure apparatus of this embodiment is installed, so that the dust, chemical substances and the like are removed. In order to effectively utilize the low absorption gas, the low absorption gas having a high purity may be separated from the gas GC discharged by the gas aspirator 7, and the low absorption gas separated as described above may be returned to the pipings 9A, 9B to

reuse the separated low absorption gas. Especially, the low absorption gas to be reused may be supplied to the reticle stage chamber 4 and the wafer stage chamber 6, and the high purity low absorption gas, which is supplied from the first or second gas source described above, may be supplied to the gas-tight units 2, 3 and the lens barrel 5 of the projection optical system PL. Accordingly, the running cost can be further lowered, and the intensity of the exposure light beam can be maintained to be high.

Next, with reference to Fig. 2, explanation will be made for detailed arrangement and operation of each of the gas substitution units S2 to S6. The respective gas substitution units S2 to S6 are mutually constructed in the same manner except for, for example, the flow rate of the gas. Therefore, one gas substitution unit S (any one of S2 to S6), which is arbitrarily selected from the gas substitution units S2 to S6, will be explained. The gas-tight unit (any one of the gas-tight unit 2 to the wafer stage chamber 6), for which the gas substitution is performed by the gas substitution unit S, is designated as "gas-tight unit 8".

Fig. 2 shows the gas substitution unit S and the gas-tight unit 8 corresponding thereto. With reference to Fig. 2, the gas-tight unit 8, which includes a part of the optical path for the exposure light beam in the projection exposure apparatus, is connected to the gas substitution unit S via the gas supply tube Si and the gas discharge tube Se each of

which is made of, for example, special stainless steel. The gas-tight unit 8 has the gas-tight structure as described above. Almost all of the low absorption gas, which is supplied from the gas supply tube Si, is discharged through the gas discharge tube Se. Valves V12, V1, which are openable/closable respectively, are installed at intermediate positions of the gas supply tube Si and the gas discharge tube Se.

At first, the arrangement of the gas substitution unit S will be explained, while explaining the basic operation to be performed when the gas in the gas-tight unit 8 is substituted.

That is, the low absorption gases GA, GB, which are supplied to the pipings 9A, 9B from the unillustrated gas sources, arrives at an inflow port of a temperature controller 16 via openable/closable valves V9, V10 respectively and via a common openable/closable valve V11. Any one of the low absorption gas GA, the low absorption gas GB, or a mixed gas thereof can be supplied to the temperature controller 16 by opening the valve V11 and controlling the opening/closing operation of the valves V9, V10. When the valve V11 is closed, it is also possible to stop the supply of the low absorption gases GA, GB from the pipings 9A, 9B. A piping, which is installed with another openable/closable valve V7, is also connected to the inflow port of the temperature controller 16. In this situation, when the valve

V7 is closed, and the valves V12, V11 are opened, then the low absorption gas, which is temperature-controlled to have a predetermined temperature by the temperature controller 16, is supplied to the interior of the gas-tight unit 8 via an outflow port and the gas supply tube Si.

When the air remains in the gas-tight unit 8 at the beginning, then the air in the gas-tight unit 8 is extruded in accordance with the inflow of the low absorption gas into the gas-tight unit 8, and the air is discharged to an inflow port of a concentration meter 11A for the residual gas via the gas discharge tube Se. Pipings, which are installed with openable/closable valves V2, V3, are connected to an outflow port of the concentration meter 11A. The piping, which is installed with the valve V2, is connected to a gas feed pump 12. The piping, which is installed with the valve V3, is connected to the gas aspirator 7 via a discharging piping 9C (corresponding to the pipings 9C1, 9C2 shown in Fig. 1). The gas feed pump 12 is connected to a piping installed with an openable/closable valve V8 and the piping installed with the valve V7 via a dustproof filter 13, a chemical filter 14, an absorptive gas-removing filter 15, and a concentration meter 11B for the residual gas. The piping, which is installed with the valve V8, is connected to the gas aspirator 7 via the discharging piping 9C. A piping, which is installed with an openable/closable valve V4, is also connected to an inflow port of the gas feed pump 12. This piping is connected to

the pipings 9A, 9B via openable/closable valves V5, V6 respectively.

Each of the concentration meters 11A, 11B is a sensor constructed by combining, for example, an oxygen concentration meter and a hygrometer (or a dew point recorder may be used) as a concentration meter for steam. Each of the concentration meters 11A, 11B measures the concentration of the absorptive gas (for example, oxygen and steam in this embodiment) in the gas passing through the interior thereof. Results of the measurement are supplied to a control unit 17 composed of a microcomputer. However, in this embodiment, the substitution is performed with the first low absorption gas GA, and then the substitution is performed with the second low absorption gas GB. Therefore, a concentration sensor for the first low absorption gas GA (nitrogen gas) is also incorporated into each of the concentration meters 11A, 11B. The control unit 17 controls the opening/closing operation for the valves V1 to V12 on the basis of the measured values of the concentrations of the absorptive gas and the first low absorption gas GA and the control information supplied from the main control system 18.

In this embodiment, the basic operation is performed as follows in order to extrude the residual air in the gas-tight unit 8 after assembling the apparatus or before running the apparatus. That is, the valve V2 is closed, and the valve V3 is opened. The residual air in the gas-tight unit 8, which

is discharged through the concentration meter 11A, is discharged by the gas aspirator 7 via the piping 9C. When the gas supply as described above is continued for several minutes to several hours, the residual concentration of the residual air in the gas-tight unit 8, especially of oxygen and steam having intense absorption with respect to the vacuum ultraviolet light beam can be lowered to be in an order of ppm.

As for the type of the low absorption gas for performing the substitution for the interior of the gas-tight unit 8, it is preferable to use the gas which has a characteristic of small pressure-dependent change and a characteristic of small temperature-dependent change of the refractive index, in order to optically stabilize the optical path. Further, it is preferable to use the gas which has a large coefficient of thermal conductivity and which has a low molecular weight, in view of the cooling effect on the optical system (lens, mirror). The most preferred gas, which satisfies both of the requirements, is helium. Other rare gases such as neon and argon are also appropriate. However, the rare gas such as helium is expensive. Therefore, the consumption of a large amount of the gas, which is caused by the continuous flow as described above, is not preferred, because the running cost is increased.

Accordingly, the following system is adopted in this embodiment. That is, the gas supply is firstly performed

with the cheap price first low absorption gas GA (nitrogen gas) to discharge almost all of the absorptive gas in the gas-tight unit 8. After that, the gas supply is switched to the supply with the high performance second low absorption gas GB (rare gas, desirably helium) to fill the interior of the gas-tight unit 8 with the rare gas. In this procedure, even when nitrogen remains in an order of several % after the substitution with the rare gas, the exposure light flux is not badly affected thereby, because the absorption by nitrogen is small with respect to the exposure light beam. Therefore, it is possible to greatly economize the amount of use of the expensive rare gas which is required to perform the substitution with the rare gas. It is possible to greatly reduce the cost for the gas in the working operation.

Specifically, the following method is available. At first, in step 201 shown in Fig. 5, the valves V9, V11, V12, V1, V3 shown in Fig. 2 are opened, and the valves V10, V7, V2 are closed to supply the first low absorption gas GA to the interior of the gas-tight unit 8. The routine proceeds to step 203 at a stage at which the concentration of the absorptive gas such as oxygen and steam measured by the concentration meter 11A is not more than a predetermined value DA1 (for example, 5 ppm) in step 202. The valve V9 is closed, and the valve V10 is opened to switch the gas to be supplied to the interior of the gas-tight unit 8 to the second low absorption gas GA (rare gas). The supply of the

second low absorption gas GB is continued until the residual concentration of the first low absorption gas GA measured in step 204 is not more than an allowable value DA2 (for example, several %). Accordingly, the gas in the gas-tight unit 8 is substituted with the second low absorption gas GB at a high concentration. The transmittance of the exposure light beam passing through the optical path in the gas-tight unit 8 is maintained to be high. In this state, the exposure is performed in step 205.

As for the residual concentration of the first low absorption gas GA after the supply of the second low absorption gas GB, no special inconvenience arises even when several % of the first low absorption gas GA remains. Therefore, it is also possible to complete the supply of the second low absorption gas GB by managing only the supply time. When only the supply time is managed as described above, the structure of the apparatus is simplified, because it is unnecessary that the concentration meters 11A, 11B possess the function to measure the concentration of the first low absorption gas GA.

In the case of the gas substitution based on the gas supply as described above, a long period of time is required in some cases in order to sufficiently lower the residual concentration of the absorptive gas. In order to solve such a problem, a method is also available, in which the interior of the gas-tight unit 8 is firstly evacuate in vacuum when

the gas substitution is performed, and the low absorption gas GA, GB is charged thereto. Of course, in this case, it is necessary that each of the gas-tight units (gas-tight units 2, 3, reticle stage chamber 4, lens barrel 5 of projection optical system PL, and wafer stage chamber 6) has a strong structure capable of enduring the difference in pressure between the vacuum at the inside and the approximate atmospheric pressure at the outside.

As described above, the method, in which the gas substitution is performed after performing the evacuation in vacuum, has such a merit that the required time is short and it is enough to require a small amount of the low absorption gas as well. However, the following fear may arise. That is, the release gas containing impurities is generated from various structural members in the gas-tight unit 8 during the process of the vacuum evacuation for the interior of the gas-tight unit 8. The generated impurities adhere to the surface of the optical member such as the lens and the mirror, and cloudy substances are formed on the surface of the optical member. Consequently, the transmittance of the exposure light beam is lowered.

Accordingly, in this embodiment, the following method is adopted for the operation to perform the gas substitution in a short period of time. That is, the pressure in the gas-tight unit 8, which is obtained by the first reduction of pressure, is kept within a range of low vacuum of such an

extent that no release gas is generated from various structural members to avoid any pollution of the optical member.

Specifically, in order to reduce the pressure in the gas-tight unit 8 to a predetermined pressure P2 (P2 is lower than P1) in step 211 shown in Fig. 5 assuming that the pressure in the gas-tight unit 8 before starting the pressure reduction is P1 (P1 is approximately 1 atm., i.e., P1 is about 900 hPa to 1100 hPa), the valves V7, V11, V2 shown in Fig. 2 are closed, and the valves V12, V1, V3 are opened to operate the gas aspirator 7 disposed on the extension of the discharging piping 9C. In order to improve the gas-aspirating ability in this situation and suppress, for example, any oil emission from an aspiration mechanism in the gas aspirator 7, a vacuum pump (dry pump) may be further installed in the vicinity of the valve V3 on the piping 9C to reduce the pressure by using this vacuum pump. A pressure gauge 19 for measuring the gas pressure in the gas-tight unit 8 is installed at an arbitrary position in the piping ranging from the valve V12 to the gas-tight unit 8, in the piping ranging from the gas-tight unit 8 to the valve V1, or at the inside of the gas-tight unit 8. The pressure, which is measured by the pressure gauge 19, is supplied to the control unit 17. The control unit 17 controls the pressure reduction and the pressure application on the basis of the measured value of the gas pressure.

In this embodiment, the gas pressure in the gas-tight unit 8 is changed as depicted by a solid polygonal line shown in Fig. 4. In Fig. 4, the horizontal axis indicates the elapsed time t, and the vertical axis indicates the gas pressure P in the gas-tight unit 8. The pressure reduction in step 211 is started at the point of time t0 shown in Fig. 4, and the pressure reduction is performed until the gas pressure P in the gas-tight unit 8 arrives at the predetermined gas pressure P2 at the point of time t1. After that, the valve V3 shown in Fig. 2 is closed to stop the pressure reduction. The predetermined gas pressure P2 is a low vacuum gas pressure of such an extent that no release gas is generated from various structural members, the numerical value of which is about 50 Pa to 10 kPa.

Subsequently, the routine proceeds to step 212 shown in Fig. 5. At the point of time t2 shown in Fig. 4, the valve V3 shown in Fig. 2 is closed, and the valve V10 (or V9) and the valve V11 are opened to supply the low absorption gas GB (or GA) to the interior of the gas-tight unit 8. The interior of the gas-tight unit 8 is filled with the low absorption gas until a gas pressure P3, which is higher than the gas pressure P2, is obtained. The gas pressure P3 is a gas pressure which is lower than the gas pressure P1. After the interior of the gas-tight unit 8 has the gas pressure P3 at the point of time t3, the valve V10 (or V9) and the valve V11 are closed to complete the filling operation with the

absorptive gas. In step 213 subsequent thereto, it is judged whether or not steps 211, 212 are repeated m times as a predetermined number of times (m is an integer of not less than 2, and m = 3 in this embodiment). If the number of repetition does not arrive at m, the routine returns to step 211. The valve V3 is opened again at the point of time t4 to reduce the pressure in the gas-tight unit 8 to the gas pressure P2 (point of time t5). After that, in step 212, the interior of the gas-tight unit 8 is filled with the low absorption gas up to the gas pressure P3 from the point of time t6 to the point of time t7.

After that, in this embodiment, steps 211, 212 are repeatedly executed from the point of time t8 to a point of time exceeding t10. Subsequently, the routine proceeds to step 214. The interior of the gas-tight unit 8 is finally filled with the low absorption gas GB (or GA) until the initial gas pressure P1 is obtained. As a result, the interior of the gas-tight unit 8 has the gas pressure P1 at the point of time t11, and the gas substitution comes to end. After that, the exposure is performed in step 215. Usually, it is desirable that the gas pressure P1, at which the exposure is finally performed, is the atmospheric pressure (approximately 1 atm.). However, even in the case of the vacuum ultraviolet region, when a light beam, which has a wavelength shorter than that of the F_2 laser, is used as the exposure light beam, it is desirable to set a gas pressure

slightly lower than the atmospheric pressure, in order to avoid any absorption by the gas.

In this system, it is possible to avoid the generation of the release gas from the internal structural members, because the pressure in the gas-tight unit 8 is not reduce to the high vacuum. On the other hand, in the case of the pressure reduction performed until the low vacuum (gas pressure P2) is obtained, any absorptive gas remains in the gas-tight unit 8. However, in this embodiment, the residual concentration of the absorptive gas can be reduced with the m-th power of the gas pressure ratio (= P2/P3) (exponentiation of the number of repeated times) by repeating, m times, the pressure reduction to the gas pressure P2 and the filling operation with the low absorption gas to the gas pressure P3 which is higher than the gas pressure P2.

In the embodiment described above, the concentration meters 11A, 11B for the residual gas are used in Fig. 2, and the concentration meters 11A, 11B include the sensor sections such as the oxygen concentration meters and the steam concentration meters. Some of the sensor sections do not endure the pressure reduction due to their structures. For example, each of the oxygen concentration meter based on the polarograph system and the oxygen concentration meter based on the zirconia system has a structure which cannot endure the pressure reduction. Accordingly, when the operation for

performing the gas substitution is executed after performing the pressure reduction process as in steps 211 to 214 shown in Fig. 5, and when the concentration meter is provided with the sensor section which does not endure the pressure reduction, then it is necessary that the sensor section of the concentration meter 11A is installed at a position capable of being separated from the main flow passage of the gas flow passage by means of, for example, valves.

Fig. 3 shows a method of installation in such a case. In the concentration meter 11A for the residual gas shown in Fig. 3, two switching type valves V13, V14, which are operated under the control of the control unit 17, are provided between a piping 113 for the inflow gas and a piping 116 for the outflow gas. One of the pipings between the both valves V13, V14 is designated as "main flow passage 114", and the other piping is designated as "subsidiary flow passage 115". The sensor section 112 for the residual gas, which includes the oxygen concentration meter, the steam concentration meter, and the nitrogen concentration meter, is installed on the subsidiary flow passage 115.

In this arrangement, when the pressure reduction is performed upon the gas substitution, the switching type valves V13, V14 are operated so that the main flow passage 114 is communicated with the inflow piping 113 and the outflow piping 116, and the subsidiary flow passage 115 is shut off from the inflow piping 113 and the outflow piping

116. That is, the subsidiary flow passage 115 is separated from the main flow passage 114 so that the sensor section 112 for the residual gas is prevented from the pressure reduction. After completion of the gas substitution, the switching type valves V13, V14 are operated so that the subsidiary flow passage 115 is communicated with the inflow piping 113 and the outflow piping 116 to measure the concentration of the residual gas (absorptive gas) in the gas inflowing from the gas-tight unit 8 shown in Fig. 2.

When the sensor section 112 for the residual gas is exposed to a high concentration of residual gas, then the sensor section 112 for the residual gas may be occasionally broken (for example, in the case of the oxygen sensor based on the yellow phosphorous light emission system), or the sensitivity may be occasionally deteriorated (for example, in the case of the oxygen concentration meter based on the polarograph system and the oxygen concentration meter based on the zirconia system), depending on the type of the sensor section 112 for the residual gas. Accordingly, even in the case of the apparatus based on the system in which the pressure reduction process is not performed, i.e., the gas substitution is performed only by supplying the gas, it is desirable for the arrangement of the concentration meter 11A for the residual gas that the sensor section 112 for the residual gas is capable of being separated from the main flow passage 114, as in the example shown in Fig. 3. Accordingly,

the breakage or the deterioration of the sensitivity can be avoided, which would be otherwise caused by the inflow of the high concentration of residual gas into the sensor section 112 for the residual gas at the early stage of the gas substitution. It is more preferable to provide a structure in which only the subsidiary flow passage 115 of the sensor section 112 for the residual gas can be separately subjected to substitution by means of supply of the gas.

As described above, the rare gas, which is represented by helium, is most appropriate as the gas to be charged into the optical path for the exposure light beam. However, the rare gas is expensive, and hence the following procedure can be adopted. That is, the substitution is performed with the rare gas such as helium for only the gas-tight unit which especially affects the performance, of the respective gas-tight units in the exposure apparatus which require the gas substitution (gas-tight units 2, 3, reticle stage chamber 4, lens barrel 5 of projection optical system PL, and wafer stage chamber 6). The substitution is performed with cheap nitrogen for the unit which does not affect the performance so much. For example, the substitution is performed with helium for the interior of the lens barrel 5 of the projection optical system PL, because the image formation performance is greatly affected therein by the change of the refractive index of the gas caused by the fluctuation of the pressure and the variation of the temperature, and by the

increase of the temperature of the lens member caused by the absorption of the exposure light beam. However, the substitution may be performed with nitrogen for the gas-tight unit 2 for surrounding the beam matching unit BMU and the gas-tight unit 3 for surrounding the illumination optical system ILU, because these gas-tight units are insensitive to the influence as described above.

The substitution may be performed with nitrogen for the reticle stage chamber 4 and the wafer stage chamber 6, because the optical path length of the image formation optical path is short, and the influence of fluctuation is scarcely exerted. However, it is preferable to perform the substitution with the rare gas such as helium, in order to avoid any bad influence of the fluctuation of the pressure and the fluctuation of the temperature on the result of measurement performed by the unillustrated interferometer for measuring the position.

In the embodiment described above, nitrogen is used as the first low absorption gas GA, and the rare gas is used as the second low absorption gas GB. However, for example, argon, which is a gas having a relatively large refractive index and a low coefficient of thermal conductivity among the rare gases, may be used as the first low absorption gas GA, and a rare gas (for example, helium or neon) other than the above may be used as the second low absorption gas GB.

When the concentration of the absorptive gas in the gas-

tight unit 8 arrives at a value of not more than the predetermined value in accordance with the process as described above, then the transmittance of the exposure light beam is improved and stabilized, and the exposure apparatus can start the exposure operation.

However, the impurity gas is continuously generated (released) from the surface of the structural member in the gas-tight unit 8 (for example, from the surface of the metal, the surfaces of the lens and the mirror, and the substrate for electronic parts), although the amount of the impurity gas is extremely minute as compared with a case in which the vacuum evacuation is performed. The gas on the optical path in the gas-tight unit 8 is polluted with the impurity gas, and the transmittance of the exposure light beam is gradually lowered.

Accordingly, in order to continuously remove the impurity as described above, it is necessary to make circulation while removing the impurity of the gas on the optical path. The gas, which is supplied from the piping 9A, 9B as described above, may be continuously used for the gas supply to maintain the gas purity. However, if such a method is adopted, the running cost is increased, because a large amount of the gas is consumed. Accordingly, in the following embodiment, explanation will be made for a mechanism for making circulation while maintaining the gas purity of the gas in the gas-tight unit 8.

The mechanism, which ranges from the valve V2 via the gas feed pump 12 to the valve V7 included in the gas flow passage shown in Fig. 2, is a mechanism to be used for the gas circulation. The mechanism will be explained in detail below.

After the concentration of the absorptive gas in the gas-tight unit 8 arrives at a value of not more than the predetermined value, the valves V9, V10, V11, V3, V4, V5, V6, V8 are closed, and the valves V2, V7 are opened to start the circulation of the gas at the inside of the gas-tight unit 8. The gas, which is discharged from the gas-tight unit 8, passes through the concentration meter 11A for the residual gas and the valve V2, and the gas is pressurized by the gas feed pump 12. Dust or the like is removed from the gas with the dustproof filter 13 such as an HEPA filter (high efficiency particulate air-filter) or a ULPA filter (ultra low penetration air-filter). After that, the gas is purified by the chemical filter 14 for removing chemical substances, such as an ammonia-removing filter and an organic matter-removing filter composed of, for example, ceramics and metal oxide powder. Oxygen and steam are removed to be in orders of ppm respectively from the gas having passed through the chemical filter 14, by means of the absorptive gas-removing filter 15 including a steam-removing filter and an oxygen-removing filter composed of metal oxide or the like. After that, the concentration of the residual gas is checked by the

concentration meter 11B for the residual gas. The gas, which has passed through the concentration meter 11B, passes through the valve V7, and the gas is subjected to temperature control by the temperature controller 16. After that, the gas passes through the valve V12, and the gas is fed to the gas-tight unit 8. The components, which range from the dustproof filter 13 to the absorptive gas-removing filter 15, correspond to the impurity-removing filter of the present invention.

In this embodiment, the gas feed pump 12 is arranged upstream from the chemical filter 14 including the organic matter-removing filter, because it is feared that any oil may be released from the gas feed pump 12 for pressurizing the gas. The chemical filter 14 is installed upstream from the absorptive gas-removing filter 15, because it is feared that oxygen or the like may be generated from the chemical filter 14 (organic matter-removing filter).

It is not necessarily indispensable to circulate all of the gas in 100 % in the gas circulation as described above. A certain amount of gas may be discharged from the circulating gas to the gas discharge tube 9C, and a corresponding amount of gas may be replenished from the pipings 9A, 9B.

A large amount of gas is also present at the inside of the gas-circulating mechanism as described above (mechanism ranging from the valve V2 via the gas feed pump 12 to the

valve V7). A large amount of gas also remains in the various filters. Therefore, in order to perform the internal gas circulation by connecting the gas-circulating mechanism to the gas-tight unit 8 simultaneously with the completion of the gas substitution for the gas-tight unit 8, it is necessary that the gas in the gas-circulating mechanism is also previously substituted with the low absorption gas.

The pipings 9A, 9B connected to the valves V5, V6, and the discharging piping (connected to the piping 9C) installed with the valve V8 constitute the equipment for substituting the gas in the gas-circulating mechanism. However, the method for the gas substitution in the gas-circulating mechanism can be performed in accordance with a variety of methods equivalent to that used for the gas substitution for the interior of the gas-tight unit 8 described above, if it is recognized that the valves V5, V6, V4, V8, V7 correspond to the valves V9, V10, V11, V3, V2 respectively. Therefore, detailed explanation for the method is omitted.

It is also desirable that the structure of the concentration meter 11B for the residual gas is equivalent to that of the concentration meter 11A for the residual gas shown in Fig. 3.

The gas substitution as described above is required not only when the assembling and the adjustment of the projection exposure apparatus are completed, for example, in the semiconductor production factory but also, for example, when

the projection exposure apparatus in working operation is restored after the maintenance. Especially, it is frequently necessary to perform the maintenance for the interior of the wafer stage chamber 6 and the interior of the reticle stage chamber 4. The early restoration after the maintenance is extremely important in order to enhance the net working rate of the apparatus.

Accordingly, this embodiment adopts an arrangement in which the space, into which the external air (air) makes invasion when the gas substitution is interrupted for the respective gas-tight units (gas-tight units 2, 3 to wafer stage chamber 6) for the purpose of maintenance, is limited as far as possible so that the restoration (gas re-substitution) is sufficiently completed in a short period of time.

That is, with reference to Fig. 2, when the maintenance is performed for the internal components in the gas-tight unit 8 (beam matching unit BMU shown in Fit. 1 to wafer stage system WST), the valves V12, V1 in the gas supply tube Si and the gas discharge tube Se for connecting the gas substitution unit S and the gas-tight unit 8 are closed so that the air, which flows into the gas-tight unit 8 during the maintenance, does not flows into the gas substitution unit S. When the maintenance is completed, the gas-tight unit 8 is subjected to the gas substitution in accordance with the same method as that used for the gas substitution described above.

Accordingly, it is possible to avoid the inflow of the air into the gas substitution unit S (gas-circulating mechanism). Therefore, the time required for the restoration is shortened.

It is also necessary to perform the maintenance for the gas-circulating mechanism in some cases. Also in such a case, for example, the valves V2, V7 are closed during the maintenance to avoid any invasion of the contaminating air into the gas-tight unit 8. Thus, it is possible to shorten the time required for the restoration.

Alternatively, valves and pipings for supplying and discharging the low absorption gas may be installed at positions among the gas feed pump 12 and the various filters 13, 14, 15 in the gas-circulating mechanism so that the respective parts may be subjected to the gas substitution in an independent manner. Accordingly, it is also possible to further shorten the restoration time upon the maintenance or the exchange of parts.

Another feature will be described below. In the factory in which the projection exposure apparatus is installed, if the electric power supply is cut off, if the supply of the low absorption gas is stopped, if the purity of the low absorption gas is lowered, or if any disaster such as earthquake takes place, then it is feared that the purity of the low absorption gas in the apparatus may be inversely lowered by continuing the circulation of the gas as described

above.

Accordingly, it is desirable that the internal gas is enclosed in each of the sections by closing, for example, the valves V12, V1, V2, V4, V7, V8 in synchronization with the occurrence of the emergency as described above. Specifically, it is recommended to provide a mechanism for closing each of the valves in cooperation with, for example, an unillustrated power source monitor, a pressure gauge installed for each of the pipings 9A, 9B, a flow meter, an impurity concentration meter, a fire alarm in the factory, and an earthquake recorder.

It is needless to say that the valves described in the foregoing embodiment are opened/closed automatically in all cases on the basis of the command from the control unit 17 of the exposure apparatus, and the operation sequence for each of the valves is also based on the program of the main control system 18.

In the exposure apparatus of the embodiment described above, it is necessary that the gas in the space including the optical path is substituted with the low absorption gas so that the residual concentration of the absorptive gas such as oxygen is not more than about several ppm. Accordingly, it is necessary that the concentration of the absorptive gas such as oxygen contained in the low absorption gas to be used is suppressed to be not more than about 1 ppm. Therefore, when the low absorption gas, which is supplied via the

factory piping in the factory in which the projection exposure apparatus is installed, does not satisfy the foregoing condition, it is necessary to install a gas-purifying unit such as an oxygen-removing filter and a steam-removing filter between the factory piping and the pipings 9A, 9B for supplying the gas.

In the embodiment described above, for example, the larger the surface area of the structural material in the gas-tight unit 8 is, the larger the number of molecules of adhered light-absorbing substance is. Therefore, it is recommended that the optical path space is designed so that no fine structure is provided in order to decrease the surface area. For the same reason, it is preferable that the surface roughness of the structural material is reduced by performing the polishing by means of a method including the mechanical polishing, the electrolytic polishing, the buffing, the chemical polishing, and GBB (Glass Bead Blasting). After applying the treatment as described above, an artifice may be applied to reduce the amount of the release gas from the surface of the structural material by previously washing the surface of the structural material before the exposure of the circuit pattern in accordance with a technique including, for example, the ultrasonic washing, the spray of fluid such as clean dry air, and the vacuum heating degassing (baking).

It is also known that the light-absorbing substance such

as hydrocarbon and halide is released, for example, from the adhesive, the seal member (for example, the O-ring), and the electric wire-coating substance existing in the optical path space. In the embodiment described above, when the amount of generation of the light-absorbing substance is fundamentally suppressed beforehand by effecting the countermeasure including, for example, the exclusion of the installation of, for example, the adhesive, the seal member (for example, the O-ring), and the electric wire-coating substance containing hydrocarbon and halide in the optical path space as far as possible, and the utilization of materials which generate less release gas, the effect of the present invention is obtained more remarkably in the same manner as in the treatment against water molecules described above.

It is desirable that each of the casing (alternatively a cylindrical member) for constructing those ranging from the gas-tight unit 2 to the wafer stage chamber 6 shown in Fig. 1 and the pipings for supplying the helium gas or the like is formed of a material which generates the minimum amount of impurity gas (release gas) including, for example, stainless steel (the inside thereof may be further oxidized to form chromium oxide or the like) and various polymers such as those of tetrafluoroethylene, tetrafluoroethylene-terfluoro(alkyl vinyl ether), or tetrafluoroethylene-hexafluoropropene copolymer.

Further, it is desirable that the cable or the like for

supplying the electric power, for example, to the driving mechanism (for example, the reticle blind and the stage) in each of the casings is coated with a material which generates the minimum amount of the impurity gas (release gas) in the same manner as described above.

In the embodiment described above, the spaces between the plurality of optical elements for constructing the illumination optical system ILU shown in Fig. 1 or the plurality of optical elements for constructing the projection optical system PL may be formed as tightly enclosed lens chambers (corresponding to gas-tight chambers) respectively. The gas supply tube Si and the gas discharge tube Se from the gas substitution unit may be provided for each of the lens chambers to perform the substitution with the low absorption gas for each of the lens chambers in an independent manner.

The concentration of the light-absorbing substance may be managed with mutually different allowable concentrations for the gas-tight unit 3 for surrounding the illumination optical system ILU shown in Fig. 1, the reticle stage chamber 4, the space at the inside of the lens barrel 5 of the projection optical system PL, and the space between the projection optical system PL and the wafer 61 (wafer stage chamber 61). In this procedure, the light-absorbing substance may be managed in the reticle stage chamber 4 and the wafer stage chamber 6 with an allowable concentration higher than an allowable concentration for the interior of

the gas-tight unit 3 and the projection optical system PL, because the reticle stage chamber 4 and the wafer stage chamber 6 are provided with the movable mechanisms such as the stages.

The laser interferometer for measuring the position of the stage is provided for each of the reticle stage chamber 4 and the wafer stage chamber 6. In such an arrangement, when the concentration of the low absorption gas is changed in the optical path for the measuring light beam of the laser interferometer, the change possibly causes a factor of fluctuation of the optical path. Accordingly, it is desirable that a concentration sensor for the low absorption gas is arranged in the optical path to manage the concentration of the low absorption gas in the vicinity of the optical path on the basis of an obtained measured value.

It is clear that the present invention is not limited to the projection exposure apparatus, which is also applicable, for example, to an exposure apparatus of the proximity system and an exposure apparatus of the contact system.

In the embodiment described above, the refracting system is used for the projection optical system PL. However, a reflecting system or a cata-dioptric system may be used for the projection optical system PL. Especially, when a cata-dioptric system, which includes a refracting system and two reflecting mirrors having apertures in the vicinity of the optical axis respectively, is used for the projection optical

system PL, as disclosed in Japanese Patent Application No. 10-370143 filed by the present applicant, the projection optical system PL can be constructed as a normal cylinder type in the same manner as in the refracting system. Therefore, the substitution with the low absorption gas for the interior can be efficiently performed. The magnification of the projection optical system is not limited to the reduction magnification, which may be 1 x magnification or expansion.

The projection exposure apparatus in the embodiment described above is assembled by adjusting the illumination optical system and the projection optical system, and connecting the respective constitutive elements electrically, mechanically, or optically. Further, as shown in Fig. 1, the gas-tight unit 2, the gas-tight unit 3, the reticle stage chamber 4, and the wafer stage chamber 6 are assembled to surround the beam matching unit BMU, the illumination optical system ILU, the reticle stage system RST, and the wafer stage system WST respectively, and the interior of the lens barrel 5 of the projection optical system PL is allowed to be in the gas-tight state. Concurrently therewith, for example, the gas substitution units S2 to S6 are assembled. Subsequently, the gas supply tubes Sin (n = 2 to 6) and the gas discharge tubes Sen are connected between the gas substitution units S2 to S6 and the corresponding gas-tight units. The pipings 9A, 9B, 9C1, 9C2 are connected to the gas substitution units S2

to S6. Accordingly, the system for substituting the gas containing the light-absorbing substance with the low absorption gas is assembled. It is desirable that the operation in this procedure is performed in a clean room in which the temperature is managed.

The tightly enclosed space in the present invention refers to a state in which any gas does not flow between the internal space and the external space, or a state in which any gas flows between the internal space and the external space but the pressure in the internal space is set to be higher than the pressure in the external state so that the inflow of the gas from the external space into the internal space is suppressed and the gas outflows to the external space from the internal space.

The wafer, for which the exposure has been performed as described above, is subjected to, for example, the development step, the pattern formation step, the bonding step, and the packaging step. Accordingly, a device such as a semiconductor element is produced. Further, the present invention is not limited to the production of the semiconductor device, which is also applicable, for example, to the production of display elements such as liquid crystal display elements and plasma displays, and thin film magnetic heads.

The projection exposure apparatus of the embodiment described above can be also preferably used when a reticle or

a mask, which is used for an exposure apparatus for producing a device to produce a semiconductor element or the like, is produced with an exposure apparatus which uses, for example, the far ultraviolet light beam (DUV light beam) or the vacuum ultraviolet light beam (VUV light beam).

The present invention is also applicable to a reduction projection exposure apparatus based on the step-and-stitch system which uses, for example, the far ultraviolet light beam or the vacuum ultraviolet light beam as an illumination light beam for the exposure.

Further, it is also allowable to use a high harmonic wave which is obtained such that a single wavelength laser in the infrared region or the visible region, which is oscillated from a DFB semiconductor laser or a fiber laser as an illumination light beam for the exposure, is amplified with a fiber amplifier doped with, for example, erbium (Er) (or both of erbium and ytterbium (Yb)), followed by wavelength conversion into an ultraviolet light beam by using nonlinear optical crystal. For example, assuming that the oscillation wavelength of the single wavelength laser is within a range of 1.544 to 1.553 μm, an 8-fold high harmonic wave within a range of 193 to 194 nm, i.e., an ultraviolet light beam having approximately the same wavelength as that of the ArF excimer laser is obtained. On the other hand, assuming that the oscillation wavelength is within a range of 1.57 to 1.58 μm, a 10-fold high harmonic wave within a range

of 157 to 158 nm, i.e., an ultraviolet light beam having approximately the same wavelength as that of the F_2 laser is obtained.

The present invention is not limited to the embodiments described above, which may be embodies in other various forms within a range without deviating from the gist or essential characteristics of the present invention. Further, all of the contents of disclosure of Japanese Patent Application No. 11-209870 filed on July 23, 1999 including the specification, claims, drawings, and abstract are cited and incorporated herein exactly as they are.

INDUSTRIAL APPLICABILITY

According to the first exposure method of the present invention, when the gas in the space including at least a part of the optical path for the exposure light beam is substituted with the gas through which the exposure light beam is transmitted, it is possible to decrease the release gas or the like generated from the surroundings of the space. Therefore, it is possible to perform the substitution in a stable manner. Therefore, especially in the exposure apparatus which uses the light beam having a wavelength in the vacuum ultraviolet region, the space including the optical path can be efficiently substituted with the low absorption gas. It is possible to suppress the absorption of

the exposure light beam. Thus, it is possible to obtain sufficient power of the exposure light beam.

According to the second exposure method of the present invention, for example, it is possible to decrease the amount of consumption of the high performance second gas by previously substituting the gas in the space including the optical path for the exposure light beam with the first gas, and then performing the substitution with the second gas. Therefore, it is possible to reduce the running cost required for the gas substitution.

According to the exposure apparatus of the present invention, it is possible to carry out the exposure method of the present invention as described above easily or efficiently.

According to the method for producing the device of the present invention, it is possible to produce the device provided with an extremely fine circuit pattern by using the exposure light beam having an extremely short wavelength. Further, it is possible to maintain the high intensity of the exposure light beam. Therefore, the throughput is improved.